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# High power diode end-pumped Yb:YAG and Tm:YAG laser systems*

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Using a scaleable diode end-pumping technology developed at LLNL we have built and demonstrated systems delivering over 100 W of cw power from both a Yb:YAG and Tm:YAG lasers. Both laser systems utilize similar pumping geometries, cooling cavities, and laser rods with diffusion bonded undoped end-caps. In addition, our compact laser designs (10x5x25 cm) use a modular architecture making these systems easy to handle and assemble.

Many potential applications motivate the development of efficient, compact cw 1 μm lasers systems with operational lifetimes capable of exceeding thousands of hours. Yb-doped laser hosts offer spectroscopic and laser properties that make them promising candidates for high energy 1 μm laser systems. In particular, Yb:YAG has a long storage lifetime of 951 μsec and a very low quantum defect resulting in less heat generation during lasing than comparable Nd based systems. In addition, the strong pump line at 940 nm makes this material highly suitable for diode pumping using InGaAs based diode lasers that are more robust than the AlGaAs based diode lasers which are used to excite Nd at approximately 808 nm. Furthermore, the 940 nm absorption feature in Yb:YAG is broader than the 808 nm absorption feature in Nd:YAG making the Yb:YAG system more forgiving in its diode wavelength specifications than a comparable Nd:YAG system.

Our Yb:YAG laser system utilized an array of 43, 1 cm long InGaAs laser diode bars packaged on silicon microchannel coolers with microlens conditioning. A lens duct was used for irradiance conditioning of the pump light and delivering it to the end of the composite rod. The composite laser rod consisted of a 50 mm long doped section with two diffusion bonded 4-6 mm long undoped YAG end pieces. The doping concentration was ~0.5% and the rod diameter was 2 mm. Our rod was housed in a cooling jacket designed to flow a coolant along the barrel of the rod. The rod was kept a temperature close to 0 °C by using a mixture of water and propanol. We produced up to 131 W of cw power with a intrinsic optical-to-optical efficiency of 25%. Beam quality, system efficiencies, and future plans will be discussed in more detail.

We have also built a Tm:YAG laser and demonstrated up to 115 W cw at 2.01 μm with an intrinsic optical-to-optical efficiency of 33%. There are many practical applications for the 2 μm light produced by this system as a result of it being strongly absorbed by water and also because it is an 'eye-safe' wavelength. The strong absorption by water makes this system an attractive candidate for performing laser surgical procedures as most tissue types are predominantly composed of liquid water. The fact that 2 μm light is 'eye-safe' makes this system attractive for laser range finding applications where other laser wavelengths could pose a safety hazard.

To allow average power scaling of the Tm:YAG laser it is not possible to pump at the peak of the absorption feature located at 785 nm. This is because the short absorption length of the pump beam would lead to high intensity thermal gradients near the input face of the rod. We have experimentally determined that wing pumping the $Tm^{3+}$ off of the main absorption feature at 805 nm can be highly effective at creating sufficient population inversions to overcome ground state reabsorption and allow for

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efficient laser operation while at the same time allowing the pump to penetrate deeply enough into the rod that the resulting thermal load becomes manageable. Another advantage of the 805 nm pump light used in this approach is the improved reliability of AlGaAs based laser diode arrays at 805 nm over those at the peak $Tm^{3+}$ absorption wavelength of 785 nm that are conventionally used in diode pumped Tm:YAG laser systems. Our pump source consisted of an array of 24 microlensed conditioned 1 cm long AlGaAs diode bars packaged on silicon microchannel coolers that produced up to 480 W of cw power at 805 nm. Our cooling design consisted of an integrated cooling path which flowed coolant through the diode arrays and into the rod housing before returning to the chiller. The Tm:YAG rod employed a composite design similar to the Yb:YAG rods described above.

Improvements in diode radiance conditioning and pump delivery efficiency, along with improved performance of the dichroic coatings used on the input faces of the rod, have increased the output power of this system beyond that of earlier versions of this laser. These improvements and performance data from the system will be further discussed in the presentation.

In addition to the development of rare earth doped dielectric-host high average power laser systems at both 1 and 2 μm we have also been working towards developing tunable mid-IR 2-3 μm lasers with a $Cr^{2+}$-doped II-VI hosts. Tunability from 2280 to 2530 nm was obtained in a ZnSe:Cr laser with an intracavity quartz birefringent filter. The laser crystal was grown using a modified Bridgman growth technique. Although this laser system is in the early stages of development we have plans to build a 1-10 W system with a diffraction grating for wider tunability.

The combination of our unique capabilities in diode development, crystal growth, and system designs have allowed us to pursue a variety of research areas of interest to the commercial, medical, and defense industries. We have developed a flexible diode pumping technology which utilizes low cost silicon microchannel coolers to enable high average power diode operation and a shaped cylindrical microlens technology which allows the radiance conditioning of large two-dimensional laser diode arrays. The flexibility that this diode technology has brought to pump power generation in both average power and pump intensity have broadly expanded the number of ion-host combinations that can be efficiently excited and used in diode pumped solid state lasers.

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